BACKGROUND ON MEASUREMENTS AND CALCULATIONS

01 Introduction

This section provides a background in the mathematical rules and procedures used in making measurements and performing calculations. Topics include:

- Units: Metric vs. English
- Mass vs. Weight
- Balances and Scales
- Rounding
- Significant Figures
- Accuracy and Precision
- Tolerance

Also included is discussion of real-world applications in which the mathematical rules and procedures may not be followed.

02 Units: Metric vs. English

Basic units in SI include:

Length:	meter, m
Mass:	kilogram, kg
Time:	second, s

Derived units in SI include:

Force:	Newton, N

SI units

03 The bulk of this document uses dual units. Metric units are followed by Imperial, more commonly known as English, units in parentheses. For example: 25 mm (1 in.). Exams are presented in metric or English.

04 Depending on the situation, some conversions are exact, and some are approximate. One inch is exactly 25.4 mm. If a procedure calls for measuring to the closest 1/4 in., however, 5 mm is close enough. We do not have to say 6.35 mm. That is because 1/4 in. is half way between 1/8 in. and 3/8 in. – or half way between 3.2 and 9.5 mm. Additionally, the tape measure or rule used may have 5 mm marks, but may not have 1 mm marks and certainly will not be graduated in 6 mm increments.

Metric	English
25 mm	1 in.
1 kg	2.2 lb
1000 kg/m^3	62.4 lb/ft^3
25 MPa	3600 lb/in.^{2}

Some approximate conversions

In SI (Le Systeme International d'Unites), the basic unit of mass is the kilogram (kg) and the basic unit of force, which includes weight, is the Newton (N). Mass in this document is given in grams (g) or kg. See the section below on "Mass vs. Weight" for further discussion of this topic.

Mass vs. Weight

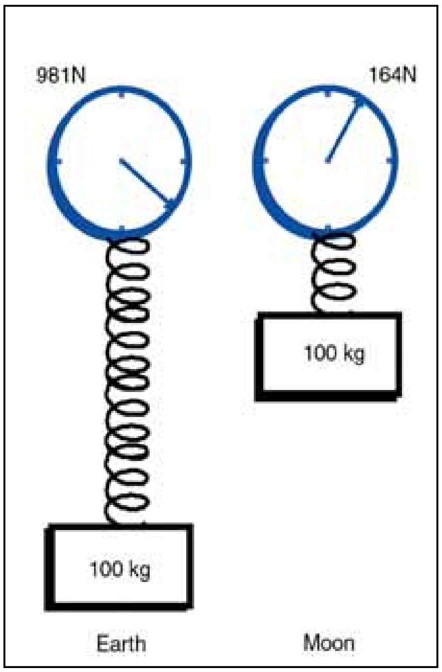
05 The terms mass, force, and weight are often confused. Mass, m, is a measure of an object's material makeup, and has no direction. Force, F, is a measure of a push or pull, and has the direction of the push or pull. Force is equal to mass times acceleration, a.

06

$$F = ma$$

Weight, W, is a special kind of force, caused by gravitational acceleration. It is the force required to suspend or lift a mass against gravity. Weight is equal to mass times the acceleration due to gravity, g, and is directed toward the center of the earth.

$$W = mg$$



Comparison of mass and weight

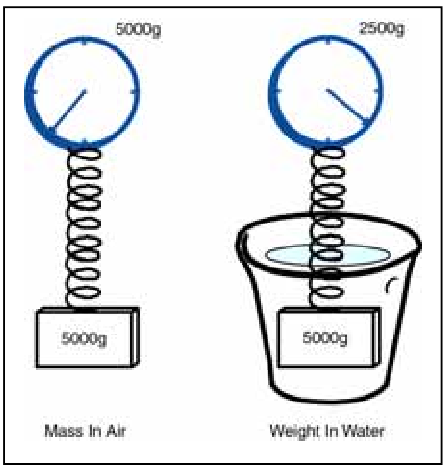
In SI, the basic unit of mass is the kilogram (kg), the units of acceleration are meters per square second (m/s^2), and the unit of force is the Newton (N). Thus a person having a mass of 84 kg subject to the standard acceleration due to gravity, on earth, of 9.81 m/s^2 would have a weight of:

$$W = (84.0 \text{ kg})(9.81 \text{ m/s}^2) = 824 \text{ kg-m/s}^2 = 824 \text{ N}$$

07 In the English system, mass can be measured in pounds-mass (lb_m), while acceleration is in feet per
08 square second (ft/s^2), and force is in pounds-force (lb_f). A person weighing 185 lb_f on a scale has a mass of 185 lb_m when subjected to the earth's standard gravitational pull. If this person were to go to the moon, where the acceleration due to gravity is about one-sixth of what it is on earth, the person's weight would be about 31 lb_f, while his or her mass would remain 185 lb_m. Mass does not depend on location, but weight does.

While the acceleration due to gravity does vary with position on the earth (latitude and elevation), the variation is not significant except for extremely precise work – the manufacture of electronic memory chips, for example.

As discussed above, there are two kinds of pounds, lb_m and lb_f. In laboratory measurements of mass, the gram or kilogram is the unit of choice. But, is
09 this mass or force? Technically, it depends on the instrument used, but practically speaking, mass is the result of the measurement. When using a scale, force is being measured – either electronically by the stretching of strain gauges or mechanically by the stretching of a spring or other device. When using a balance, mass is being measured, because the mass of the object is being compared to a known mass built into the balance.



Submerged weight

In this document, mass, not weight, is used in test procedures except when determining “weight” in water. When an object is submerged in water (as is done in specific gravity tests), the term weight is used. Technically, what is being measured is the force the object exerts on the balance or scale while the object is submerged in water (or the submerged weight). This force is actually the weight of the object less the weight of the volume of water displaced.

In summary, whenever the common terms “weight”
10 and “weighing” are used, the more appropriate
11 terms “mass” and “determining mass” are usually implied, except in the case of weighing an object submerged in water.

12

Balances and Scales

Balances, technically used for mass determinations, and scales, used to weigh items, were discussed briefly above in the section on “Mass vs. Weight.” In field operating procedures, we usually do not differentiate between the two types of instruments. When using either one for a material or object in air, we are determining <u>mass</u>. For those procedures in which the material or object is suspended in water, we are determining <u>weight</u> in water.

13 AASHTO recognizes two general categories of instruments. Standard analytical balances are used in laboratories. For most field operations, general purpose balances and scales are specified. Specifications for both categories are shown in
14 Tables 1 and 2.

Table 1
Standard Analytical Balances

Class	Capacity	Readability and Sensitivity	Accuracy
A	200 g	0.0001 g	0.002 g
B	200 g	0.001 g	0.002 g
C	1200 g	0.01 g	0.02 g

Table 2
General Purpose Balances and Scales

Class	Principal Sample Mass	Readability and Sensitivity	Accuracy
G2	2 kg or less	0.1 g	0.1 g or 0.1 percent
G5	2 kg to 5 kg	1 g	1 g or 0.1 percent
G20	5 kg to 20 kg	5 g	5 g or 0.1 percent
G100	Over 20 kg	20 g	20 g or 0.1 percent

15 Rounding

Numbers are commonly rounded up or down after measurement or calculation. For example, 53.67 would be rounded to 53.7 and 53.43 would be rounded to 53.4, if rounding were required. The first number was rounded up because 53.67 is closer to 53.7 than to 53.6. Likewise, the second number was rounded down because 53.43 is closer to 53.4 than to 53.5. The reasons for rounding are covered in the next section on “Significant Figures.”

If the number being rounded ends with a 5, two possibilities exist. In the more mathematically sound approach, numbers are rounded up or down depending on whether the number to the left of the 5 is odd or even. Thus, 102.25 would be rounded down to 102.2, while 102.35 would be rounded up to 102.4. This procedure avoids the bias that would exist if all numbers ending in 5 were rounded up or all numbers were rounded down. In some calculators, however, all rounding is up. This does result in some bias, or skewing of data, but the significance of the bias may or may not be significant to the calculations at hand.

Significant Figures

- General

16 A general purpose balance or scale, classified as G20 in AASHTO M 231, has a capacity of 20,000 g and an accuracy requirement of ±5 g. A mass of 18,285 g determined with such an instrument could actually range from 18,280 g to 18,290 g. Only four places in the measurement are significant. The fifth (last) place is not significant since it may change.

17 Mathematical rules exist for handling significant figures in different situations.
An example in Metric(**m**) or English(**ft**), when performing addition and subtraction, the number of significant figures in the sum or difference is determined by the least precise input. Consider the three situations shown below:

Situation 1	Situation 2	Situation 3
35.67	143.903	162
+ 423.938	- 23.6	+33.546
		- .022
= 459.61	= 120.3	= 196
not 459.608	not 120.303	not 195.524

Rules also exist for multiplication and division. These rules, and the rules for mixed operations involving addition, subtraction, multiplication, and/or division, are beyond the scope of these materials. AASHTO covers this topic to a certain extent in the section called “Precision” or “Precision and Bias” included in many test methods, and the reader is directed to those sections if more detail is desired.

18 • Real World Limitations

While the mathematical rules of significant digits have been established, they are not always followed. For example, AASHTO Method of Test T 176, *Plastic Fines in Graded Aggregates and Soils by the Use of the Sand Equivalent Test*, prescribes a method for rounding and significant digits in conflict with the mathematical rules.

In this procedure, readings and calculated values are always rounded up. A clay reading of 7.94 would be rounded to 8.0 and a sand reading of 3.21 would be rounded to 3.3. The rounded numbers are then used to calculate the Sand Equivalent, which is the ratio of the two numbers multiplied by 100. In this case:

$$\frac{3.3}{8.0} \times 100 = 41.250...,$$

rounded to 41.3 and reported as 42

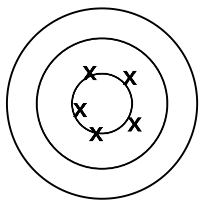
$$(\text{Not}: \frac{3.21}{7.94} \times 100 = 40.428...,$$

rounded to 40.0 and reported as 40)

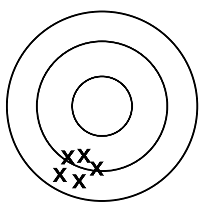
It is extremely important that engineers and technicians understand the rules of rounding and significant digits just as well as they know procedures called for in standard test methods.

Accuracy and Precision

19 Although often used interchangeably, the terms
accuracy and precision do not mean the same thing.
In an engineering sense, accuracy denotes nearness
to the truth or some value accepted as the truth,
20 while precision relates to the degree of refinement
or repeatability of a measurement.



ACCURATE BUT NOT PRECISE, SCATTERED



PRECISE BUT NOT ACCURATE, BIASED

Two bullseye targets are shown to the left. The upper one indicates hits that are scattered and, yet, are very close to the center. The lower one has a tight pattern, but all the shots are biased from the center. The upper one is more accurate, while the lower one is more precise. A biased, but precise, instrument can often be adjusted physically or mathematically to provide reliable single measurements. A scattered, but accurate, instrument can be used if enough measurements are made to provide a valid average.

Consider the measurement of the temperature of
boiling water at standard atmospheric pressure by
21 two thermometers. Five readings were taken with
each, and the values were averaged.

Thermometer No. 1	Thermometer No. 2
101.2° 214.2°	100.6° 213.1°
101.1° 214.0°	99.2° 210.6°
101.2° 214.2°	98.9° 210.0°
101.1° 214.0°	101.0° 213.8°
101.2° 214.2°	100.3° 212.5°
AVG = 101.2° 214.2°	AVG = 100.0° 212°

No. 1 shows very little fluctuation, but is off the
22 known boiling point (100°C or 212°F) by 1.2°C or
2.2°F. No. 2 has an average value equal to the
known boiling point, but shows quite a bit of
fluctuation. While it might be preferable to use
neither thermometer, thermometer No. 1 could be

employed if 1.2°C or 2.2°F were subtracted from each measurement. Thermometer No. 2 could be
23 used if enough measurements were made to provide a valid average.

24 Engineering and scientific instruments should be calibrated and compared against reference standards periodically to assure that measurements are accurate. If such checks are not performed, the accuracy is uncertain, no matter what the precision. Calibration of an instrument removes fixed error,
25 leaving only random error for concern.

Tolerance

Dimensions of constructed or manufactured objects,
26 including laboratory test equipment, cannot be specified exactly. Some tolerance must be allowed. Thus, procedures for including tolerance in addition/subtraction and multiplication/division operations must be understood.

- Addition and Subtraction

  27 When adding or subtracting two numbers that individually have a tolerance, the tolerance of the sum or difference is equal to the sum of the individual tolerances.

  An example in Metric(**m**) or English(**ft**), if the distance between two points is made up of two parts, one being 113.361 ±0.006 and the other being 87.242 ±0.005 then the tolerance of the sum (or the difference) is:

  $$(0.006) + (0.005) = 0.011$$

  and the sum would be 200.603 ±0.011.

- Multiplication and Division

  28 To demonstrate the determination of tolerance again in either Metric(**m**) or English(**ft**) for the product of two numbers, consider determining the area of a rectangle having sides of 76.254

±0.009 and 34.972 ±0.007. The percentage variations of the two dimensions are:

$$\frac{0.009}{76.254} \times 100 = 0.01\% \qquad \frac{0.007}{34.972} \times 100 = 0.02\%$$

The sum of the percentage variations is 0.03 percent – the variation that is employed in the area of the rectangle:

Area =
2666.8 (m^2 or ft^2) ±0.03 percent = 2666.8 ± 0.8 (m^2 or ft^2).

- Real World Applications

29 Tolerances are used whenever a product is manufactured. For example, the mold used for determining soil density in AASHTO T 99 has a diameter of 101.60 ±0.41 mm(4.000 ±0.016 in) and a height of 116.43 ±0.13 mm(4.584 ±0.005 in).

Using the smaller of each dimension results in a volume of:

(π/4) (101.19 mm)^2 (116.30 mm) =
935,287 mm^3 or 0.000935 m^3

(π/4) (3.984 in)^2 (4.579 in) =
57.082in^3 or 0.0330 ft^3

Using the larger of each dimension results in a volume of:

(π/4) (102.01 mm)^2 (116.56 mm) =
952,631 mm^3 or 0.000953 m^3

(π/4) (4.016 in)^2 (4.589 in) =
58.130 in^3 or 0.0336 ft^3

The average value is 0.000944 m^3 (0.0333), and AASHTO T 99 specifies a volume of:

0.000943 ±0.000008 m^3
or a range of
0.000935 to 0.000951 m^3

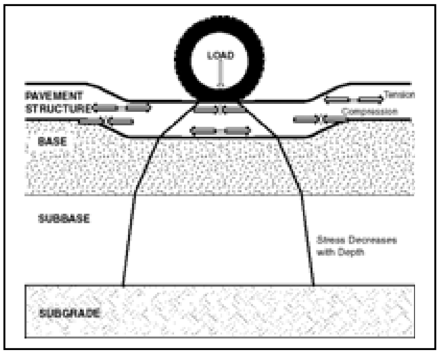
0.0333 ±0.0003 ft^3
or a range of
0.0330 to 0.0336 ft^3

Because of the variation that can occur, some agencies periodically calibrate molds, and make adjustments to calculated density based on those calculations.

Summary

Mathematics has certain rules and procedures for making measurements and performing calculations that are well established. So are standardized test procedures. Sometimes these agree, but occasionally, they do not. Engineers and technicians must be familiar with both, but must follow test procedures in order to obtain valid, comparable results.

BASICS OF COMPACTION AND DENSITY CONTROL



Load distribution in roadway cross section

Grading

01 Introduction

02 Roadways are constructed in layers. The first layer
is the subgrade, or naturally present material. Next
comes the subbase, material usually having better
03 structural, drainage, and other properties than the
subgrade. This material is sometimes a select
material. Above the subbase is placed the base,
material of even better quality than the subbase.
Finally there is the pavement consisting of either
hot mix asphalt (HMA) or portland cement concrete
(PCC). In this layered system, structural or load
bearing properties improve as we move up from
subgrade to pavement. The result is a roadway
structure that supports traffic without undergoing
excessive surface deflection and/or long term
settlement.

Variations to this layering can occur as in roadways constructed on high quality subgrade in which the subbase layer is eliminated. Also to be considered is “embankment”, material between the naturally occurring subgrade and the subbase or base, that is added in “fill” sections of the roadway where the finished road is substantially above original grade.

04 Stability and durability of roadways is greatly
dependent on the finished density of the various
components. Low-density subgrade, subbase, base,
05 or embankment will lead to excessive surface
deflection under load and/or long term settlement in
an amount higher than anticipated. However,
compacting these elements to densities higher than
necessary is expensive in both time and money.

Quality of roadways also depends greatly on the pavement. In HMA roadways, the density of the HMA plays a significant role in the overall ability to support load and provide long term service. HMA pavement specifications include detail on density as well as percent voids. Under-compaction

Cracking

Sheepsfoot roller

Steel roller

06 results in low density and high void content. An
under-compacted pavement will have low strength,
reduced durability, high deformation, and high
permeability leading to problems such as rutting,
ravelling, and freeze-thaw damage. Over-
07 compaction results in high density and low void
content. This pavement may bleed, rut, crack, or
have premature failure.

For these reasons, a basic understanding of
compaction theory and a thorough knowledge of
testing methods is necessary for those involved with
08 construction of embankments and bases, as well as
HMA pavement. Compaction equipment and
techniques depend on the type of material.
Cohesive soils, such as clay, and cohesionless soils,
such as gravel, require different compaction
methods, and different equipment may be used on
HMA than on soils.

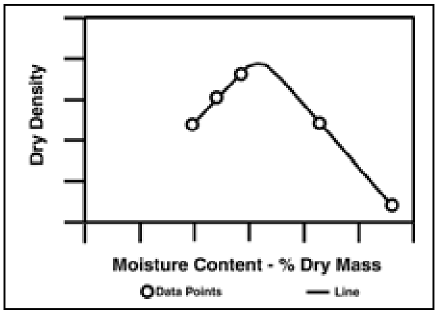
09 Fine-Grained Soils

For fine-grained soils that contain a significant amount of cohesion and little or no internal friction, density depends on compactive effort and moisture content. With these soils, moisture-density relations are key, and two similar test methods are used to determine the relationship between soil moisture and density.

- AASHTO T 99, the standard Proctor test
- AASHTO T 180, the modified Proctor test

10

In both methods, samples of soil are prepared at
11 several moisture contents and compacted into
molds of specified sizes using manual or
mechanical rammers delivering a specified quantity
12 of compactive energy. Knowing the moist masses
of the compacted samples and the volume of the
13 molds, moist densities can be determined. Moisture
contents of the compacted samples are determined
and used to obtain dry density values for the same
samples. Maximum dry density and optimum
moisture content for the soil are determined by
14 plotting the relationship between dry density and
moisture content.



Moisture-density curve

Construction specifications generally require that
15 the soil be compacted to some percentage of maximum dry density while being maintained at a moisture content close to the optimum. These
16 specified values will be based on AASHTO T 99, or AASHTO T 180 depending on the agency. In the field, dry density and moisture content of the material will be determined using a nuclear moisture-density gauge. The field values will be compared to the specifications to determine conformance with the project requirements.

Coarse-Grained Soils

Nuclear moisture-density gauge

17 For coarse-grained granular soils having little or no cohesion, compactive effort is the primary concern, and moisture content is not as significant an issue because these soils are free-draining and do not retain water. These soils are tested using two general classifications of procedures. The first includes the moisture-density methods discussed above under “Fine-grained Soils.” The second includes procedures that relate density to gradation.

Granular, free-draining materials can be tested by procedures that combine compaction and vibration, as in the Relative Density test. However, various transportation agencies have developed specialized tests that are a hybrid of moisture-density test procedures and relative density determinations, including the following:

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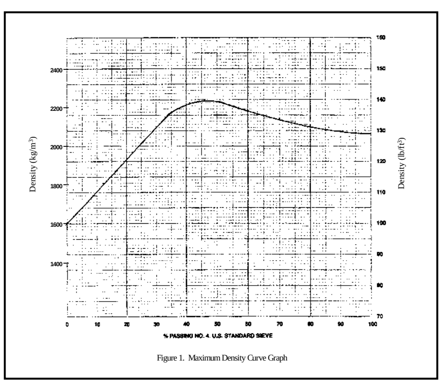
- AKDOT&PF’s ATM-12
- ITD’s T-74
- WSDOT’s TM 606
- WFLHD’s Humphrys



Maximum density curve

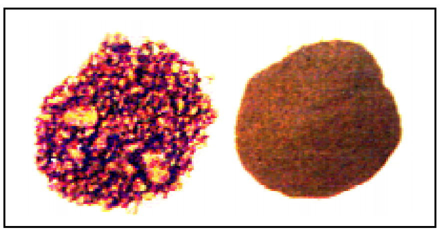
In these tests, material is compacted in a mold and in a manner similar to those used in a Proctor test, after which the material is further compacted through a combination of applied loads and
19 vibration. A laboratory maximum dry density is determined, as is the percent of material passing a
20 certain sieve such as the No. 4. A number of determinations are made for different percentages passing the specified sieve. A graph is developed in which dry density is plotted versus the

percentage of material passing that sieve. These
21 tests are conducted in the agency's central lab, and
the curve developed is a central lab function.

Construction specifications will call out a percent of maximum dry density required for the granular materials used on the job. These specified values will be based on ATM-12, T-74, TM 606, and Humphry's depending on the agency. In the field, the density of the granular material will be determined using a nuclear moisture-density gauge. The percent of material passing the specified sieve will also be determined. These values will be compared with the curve developed in the lab to determine conformance with the project specifications.

Correction for Oversize Material

22 AASHTO T 99, and AASHTO T 180 discussed
above are conducted on materials below a certain
size, either No. 4 or 3/4-in. depending on the
method. If the material to be tested includes
23 particles in excess of that size, corrections will be
required to the maximum dry densities determined.
The method used is AASHTO T 224, Correction for
Coarse Particles in the Soil Compaction Test.

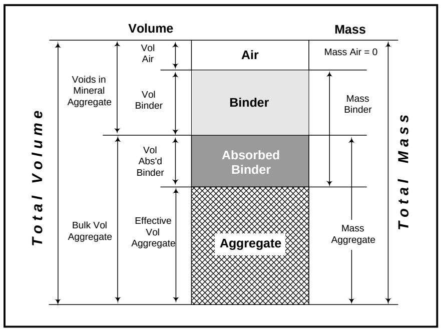


Coarse and fine material

The corrected density is actually a weighted average of the density of the smaller material passing the specified sieve and the larger material retained on the sieve. The density of the smaller material is determined using one of the methods covered above. The density of the larger material is based on knowledge of its bulk specific gravity.

Hot Mix Asphalt Pavement

24 For HMA, density depends on compactive effort as well as the mix design. The gradation and particle shape of the aggregate, the grade of asphalt binder, and the interaction of these have major influences on density and percent voids. The level of compactive effort and the equipment used depend on the mix design properties, environmental conditions and lift thickness.



HMA phase diagram

25 Construction specifications will call for obtaining a certain percentage of maximum voidless density, as determined in the mix design process, while maintaining voids within a certain range. A specification of 92 to 96 percent of maximum density and a corresponding void content between 8

26 and 4 percent is typical. In the field, the density of the compacted HMA will be determined with cores and/or calibrated nuclear density gauges and, with this information, the percent voids will be calculated. These values will be compared to the specifications to determine conformance with the project requirements.

Summary

27 Proper compaction of soil, aggregate, and hot mix asphalt is necessary for high-quality roadways. Understanding and proper performance of standardized density tests are paramount in obtaining that compaction. The Embankment and Base and/or In-Place Density technician must obtain samples and perform tests in the accepted manner in order to assure the quality of the finished roadway.

WESTERN ALLIANCE FOR QUALITY TRANSPORTATION CONSTRUCTION COURSE EVALUATION FORM

The WAQTC Transportation Technician Qualification Program would appreciate your thoughtful completion of all items on this evaluation form. Your comments and constructive suggestions will be an asset in our continuing efforts to improve our course content and presentations.

Course Title: ______________________________

Location: ______________________________

Dates: ______________________________

Your Name (Optional): ______________________________

Employer: ______________________________

Instructor(s) ______________________________

COURSE CONTENT

Will the course help you perform your job better and with more understanding? Yes Maybe No

Explain: ______________________________

____

Was there an adequate balance between theory, instruction, and hands-on application? Yes Maybe No

Explain: ______________________________

____

Did the course prepare you to confidently complete both examinations? Yes Maybe No

Explain: ______________________________

____

What was the most beneficial aspect of the course? ______________________________

____

What was the least beneficial aspect of the course? ______________________________

____

GENERAL COMMENTS

General comments on the course, content, materials, presentation method, facility, registration process, etc. Include suggestions for additional Tips!

INSTRUCTOR EVALUATION

Were the objectives of the course, and the instructional and exam approach, clearly explained? Yes Maybe No

Explain:

Was the information presented in a clear, understandable manner? Yes Maybe No

Explain:

Did the instructors demonstrate a good knowledge of the subject? Yes Maybe No

Explain:

Did the instructors create an atmosphere in which to ask questions and hold open discussion? Yes Maybe No

Explain:

GUIDANCE FOR COURSE EVALUATION FORM

The Course Evaluation Form on the following page is very important to the continuing improvement and success of this course. The form is included in each Participant Workbook. During the course introduction, the Instructor will call the participants' attention to the form, its content, and the importance of its thoughtful completion at the end of the course. Participants will be encouraged to keep notes, or write down comments as the class progresses, in order to provide the best possible evaluation. The Instructor will direct participants to write down comments at the end of each day and to make use of the back of the form if more room is needed for comments.

On the last day of the course, just prior to the written examination, the Instructor will again refer to the form and instruct participants that completion of the form after their last examination is a requirement prior to leaving. Should the course have more than one Instructor, participants should be directed to list them as A, B, etc., with the Instructor's name beside the letter, and direct their answers in the Instructor Evaluation portion of the form accordingly.

FORWARD

This module is one of five developed for the Western Alliance for Quality Transportation Construction (WAQTC) by AGRA Earth & Environmental, Inc. (AEE). These modules were developed to satisfy the training requirements prescribed by WAQTC for technicians involved in transportation projects. The five modules cover the areas of:

- Aggregate
- Concrete
- Asphalt
- Embankment and Base
- In-place Density

The modules are based upon AASHTO test methods along with procedures developed by WAQTC. They are narrative in style, illustrated, and include step-by-step instruction. There are review questions at the end of each test procedure, which are intended to reinforce the participants' understanding and help participants prepare for the final written and performance exams. Performance exam check lists are also included. The appendices include the corresponding AASHTO and WAQTC test methods.

Each module is in loose-leaf form. This allows updated and state-specific information to be added, as necessary. It will be the technician's responsibility to stay current as changes are made to this living document.

The comments and suggestions of every participant are essential to the continued success and high standards of the Transportation Technician Qualification Program. Please take the time to fill out the Course Evaluation Form as the course progresses and hand it in on the last day of class. If you need additional room to fully convey your thoughts, please use the back of the form.

The WAQTC Steering Committee

COURSE OBJECTIVES AND SCHEDULE (EMBANKMENT AND BASE)

Learning Objectives

Instructional objectives for this course include:

- Being familiar with Quality Assurance (QA) concepts
- Developing a background in measurements and calculations
- Being knowledgeable in highway materials terminology
- Respecting safety issues
- Acquiring knowledge of random sampling techniques
- Understanding the basics of compaction and density control
- Becoming proficient in the following quality control test procedures:

  FOP for AASHTO T 255
  Total Moisture Evaporable Content of Aggregate by Drying; and
  AASHTO T 265
  Laboratory Determination of Moisture Content of Soils

  FOP for AASHTO T 217
  Determination of Moisture in Soils by Means of a Calcium Carbide Gas Pressure Moisture Tester

  FOP for AASHTO T 99
  Moisture-Density Relations of Soils Using a 2.5-kg (5.5-lb) Rammer and 305-mm (12-in.) Drop;
  AASHTO T 180
  Moisture-Density Relations of Soils Using a 4.54-kg (10-lb) Rammer and 457-mm (18-in.) Drop

  FOP for AASHTO T 272
  Family of Curves -- One-Point Method

  FOP for FOP for AASHTO T 85
  Specific Gravity and Absorption of Coarse Aggregate

  FOP for AASHTO T 224
  Correction for Coarse Particles in the Soil Compaction Test

  FOP for AASHTO T 89
  Determining the Liquid Limit of Soils

  FOP for AASHTO T 90
  Determining the Plastic Limit and Plasticity Index of Soils

The overall goals of this embankment and base course are to understand compaction and density control and to be competent with specific quality control test procedures identified for the Transportation Technician Qualification Program of the Western Alliance for Quality Transportation Construction (WAQTC). Additional studies beyond this course will be required for those desiring greater in-depth knowledge of the theory behind the test procedures included herein.

Course Outline and Suggested Schedule

Day One

0800	Welcome Introduction of Instructors Introduction and Expectations of Participants
0815	WAQTC Mission and TTQP Objectives Instructional Objectives for the Course Overview of the Course Course Evaluation Form
0830	Review of Quality Assurance Concepts
0845	Background in Measurements and Calculations
0945	Break
1000	Random Sampling
1030	Basics of Compaction and Density Control
1045	Total Evaporable Moisture Content of Aggregate by Drying FOP for AASHTO T 255 Laboratory Determination of Moisture Content of Soils FOP for AASHTO T 265
1115	Determination of Moisture in Soils by Means of Calcium Chloride Gas Pressure Moisture Tester FOP for AASHTO T 217
1130	Review Questions Questions and Answers
1200	Lunch

1315	Moisture-Density Relations of Soils: Using a 2.5-kg (5.5-lb) Rammer and 305-mm (12-in.) Drop FOP for AASHTO T 99 Using a 4.54-kg (10-lb) Rammer and 457-mm (18-in.) Drop FOP for AASHTO T 180
1400	Laboratory Practice Moisture Content and Moisture-Density Relations
1645	Evaluation End of Day

Day Two

0800	Questions from the Previous Day
0815	Family of Curves -- One-Point Method FOP for AASHTO T 272
0830	Laboratory Practice Moisture Content and Moisture-Density Relations (continued)
0945	Break
1000	Specific Gravity and Absorption of Coarse Aggregate FOP for AASHTO T 85
1030	Laboratory Practice Specific Gravity and Absorption
1130	Review Questions Questions and Answers
1200	Lunch
1315	Laboratory Practice Moisture Content and Moisture-Density Relations (continued) Specific Gravity and Absorption (continued)
1645	Evaluation End of Day

Day Three

0800	Questions from Previous Day
0815	Correction for Coarse Particles in the Soil Compaction Test FOP for AASHTO T 224
0845	Determining the Liquid Limit of Soils FOP for AASHTO T 89
0900	Determining the Plastic Limit and Plasticity Index of Soils FOP for AASHTO T 90
0915	Review Questions Questions and Answers
0945	Break
1000	Laboratory Demonstration Liquid Limit and Plastic Limit
1200	Lunch
1315	Laboratory Practice Completion of any Moisture Content Determinations
1645	Evaluation End of day

Day Four

0800	Questions from Previous Day
0815	Instruction on Use of AKDOT&PF ATM-12, ITD T-74, WSDOT TM 606, or WFLHD Humphreys Curves
1000	Start of Exams Participants will break into groups so that written and practical exams may be given concurrently. Evaluation

PREFACE

This module is one of a set developed for the Western Alliance for Quality Transportation Construction (WAQTC). WAQTC is an alliance supported by the western state Transportation Departments, along with the Federal Highway Administration (FHWA) and the Western Federal Lands Highway Division (WFLHD) of FHWA. WAQTC's charter includes the following mission.

MISSION

Provide continuously improving quality in transportation construction.

Through our partnership, we will:

- Promote an atmosphere of trust, cooperation, and communication between government agencies and with the private sector.
- Assure personnel are qualified.
- Respond to the requirements of identified needs and new technologies that impact the products that we provide.

BACKGROUND

There are two significant driving forces behind the development of the WAQTC qualification program. One, there is a trend to the use of quality control/quality assurance (QC/QA) specifications. QC/QA specifications include qualification requirements for a contractor's QC personnel and will be requiring WAQTC qualified technicians. Two, Federal regulation on materials sampling and testing (23 CFR 637, *Quality Assurance Procedures for Construction*, published in June 1995) mandates that by June 29, 2000 all testing technicians whose results are used as part of the acceptance decision shall be qualified. In addition, the regulation allows the use of contractor test results to be used as part of the acceptance decision.

OBJECTIVES

WAQTC's objectives for its Transportation Technician Qualification Program include the following:

- To provide highly skilled, knowledgeable materials sampling and testing technicians.
- To promote uniformity and consistency in testing.
- To provide reciprocity for qualified testing technicians between states.
- To create a harmonious working atmosphere between public and private employees based upon trust, open communication, and equality of qualifications.

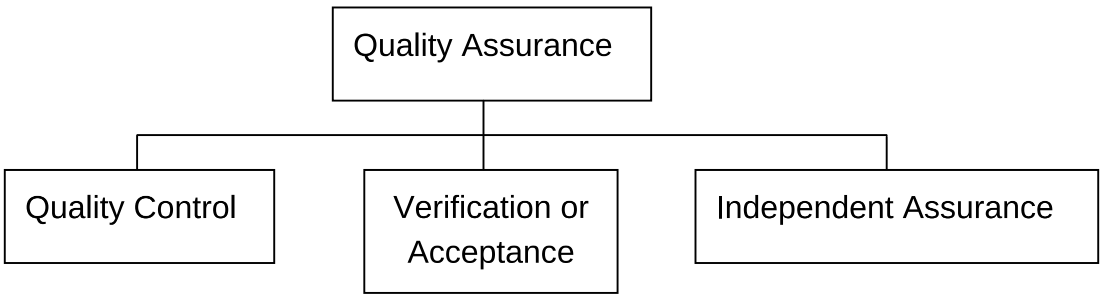
Training and qualification of transportation technicians is required for several reasons. It will increase the knowledge of laboratory, production, and field technicians — both industry and agency personnel — and increase the number of available, qualified testers. It will reduce problems associated with test result differences. Regional qualification eliminates the issue of reciprocity between states and allows qualified QC technicians to cross state lines without having the concern or need to be requalified by a different program.

The WAQTC Steering Committee

QUALITY ASSURANCE CONCEPTS

The Federal Highway Administration (FHWA) has established requirements that each 01
State Highway Agency (SHA) must develop a Quality Assurance (QA) Program that is approved by the FHWA for projects on the National Highway System (NHS). In
addition to complying with this requirement, implementing QA specifications in a 02
construction program includes the benefit of improvement of overall quality of highway and bridge construction.

A QA Program may include three separate and distinct parts as illustrated below.



03

Quality Assurance (QA) are those planned and systematic actions necessary to provide 04
confidence that a product or service will satisfy given requirements for quality.

Quality Control (QC) are those operational, process control techniques or activities that 05
are performed or conducted to fulfill contract requirements for material and equipment quality. In some states, the constructor is responsible for providing QC sampling and testing, while in other states the SHA handles QC. Where the constructor is responsible for QC tests, the results may be used for acceptance only if verified or accepted by additional tests performed by an independent group.

Verification/Acceptance consists of the sampling and testing performed to validate QC 06
sampling and testing and, thus, the quality of the product. Verification/Acceptance samples are obtained and tests are performed independently from those involved with QC. Samples taken for QC tests may not be used for Verification/Acceptance testing.

Independent Assurance (IA) are those activities that are an unbiased and independent 07
evaluation of all the sampling and testing procedures used in QC and Verification/Acceptance. IA may use a combination of laboratory certification, technician qualification or certification, proficiency samples, and/or split samples to assure that QC and Verification/Acceptance activities are valid. Agencies may qualify or certify laboratories and technicians, depending on the state in which the work is done.

RANDOM SAMPLING OF CONSTRUCTION MATERIALS

01 Significance

Sampling and testing are two of the most important functions in quality control (QC). Data from the tests are the tools with which the quality of product is controlled. For this reason, great care must be used in following standardized sampling and testing procedures.

In controlling operations, it is necessary to obtain numerous samples at various points along the production line. Unless precautions are taken, sampling can occur in patterns that can create a bias to the data gathered. Sampling at the same time, say noon, each day may jeopardize the effectiveness of any quality program. This might occur, for example, because a material producer does certain operations, such as cleaning screens at an aggregate plant, late in the morning each day. To obtain a representative sample, a reliable system of random sampling must be employed.

02

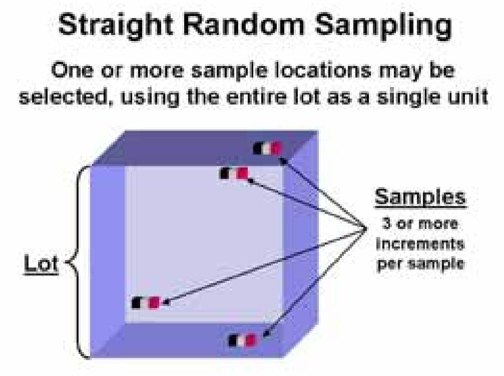
Scope

The procedure presented here eliminates bias in
sampling materials. Randomly selecting a set of
03 numbers from a table or calculator will eliminate
04 the possibility for bias. Random numbers are used
to identify sampling times, locations, or points
within a lot or sublot. This method does not cover
how to sample, but rather how to determine
sampling times, locations, or points.

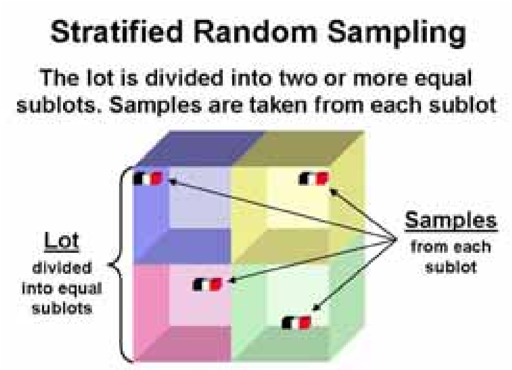
Sampling Concepts

A lot is the quantity of material evaluated by QC
05 procedures. A lot is a preselected quantity that
may represent hours of production, a quantity or
number of loads of material, or an interval of time.

A lot may be comprised of several portions that are called sublots or units. The number of sublots comprising a lot will be determined by the agency's specifications.



06 **Straight Random Sampling vs. Stratified Random Sampling:** Straight random sampling considers an entire lot as a single unit and determines each sample location based on the entire lot size. Stratified random sampling divides the lot into a specified number of sublots or units and then determines each sample location within a distinct sublot. Both methods result in random distribution of samples to be tested for compliance with the agency's specification.



Agencies stipulate when to use straight random sampling or stratified random sampling. AASHTO T 2, Sampling of Aggregates, for
07 example, specifies a straight random sampling procedure.

Picking Random Numbers from a Table

Table 1 contains pairs of numbers. The first
08 number is the "pick" number and the second is the Random Number, "RN". The table was generated with a spreadsheet and the cells (boxes at the intersection of rows and columns) containing the RNs actually contain the "random number function". Every time the spreadsheet is opened or changed, all the RNs change.

1. Select a Pick number in a random method. The first two or last two digits in the next automobile license plate you see would be one way to select. Another would be to start a digital stop watch and stop it several seconds later, using the decimal part of the seconds as your Pick number.
2. Find the RN matching the Pick number.

Picking Random Numbers with a Calculator

09 Many calculators have a built-in random number function. To obtain a random number, key in the code or push the button(s) the calculator's instructions call for. The display will show a number between 0.000 and 1.000 and this will be your random number.

TABLE 1
Random Numbers

Pick	RN	Pick	RN	Pick	RN	Pick	RN	Pick	RN
01	0.998	21	0.758	41	0.398	61	0.895	81	0.222
02	0.656	22	0.552	42	0.603	62	0.442	82	0.390
03	0.539	23	0.702	43	0.150	63	0.821	83	0.468
04	0.458	24	0.217	44	0.001	64	0.187	84	0.335
05	0.407	25	0.000	45	0.521	65	0.260	85	0.727
06	0.062	26	0.781	46	0.462	66	0.815	86	0.708
07	0.370	27	0.317	47	0.553	67	0.154	87	0.161
08	0.410	28	0.896	48	0.591	68	0.007	88	0.893
09	0.923	29	0.848	49	0.797	69	0.759	89	0.255
10	0.499	30	0.045	50	0.638	70	0.925	90	0.604
11	0.392	31	0.692	51	0.006	71	0.131	91	0.880
12	0.271	32	0.530	52	0.526	72	0.702	92	0.656
13	0.816	33	0.796	53	0.147	73	0.146	93	0.711
14	0.969	34	0.100	54	0.042	74	0.355	94	0.377
15	0.188	35	0.902	55	0.609	75	0.292	95	0.287
16	0.185	36	0.674	56	0.579	76	0.854	96	0.461
17	0.809	37	0.509	57	0.887	77	0.240	97	0.703
18	0.105	38	0.013	58	0.495	78	0.851	98	0.866
19	0.715	39	0.497	59	0.039	79	0.678	99	0.616
20	0.380	40	0.587	60	0.812	80	0.122	00	0.759

Examples of Straight Random Sampling Procedures Using Random Numbers

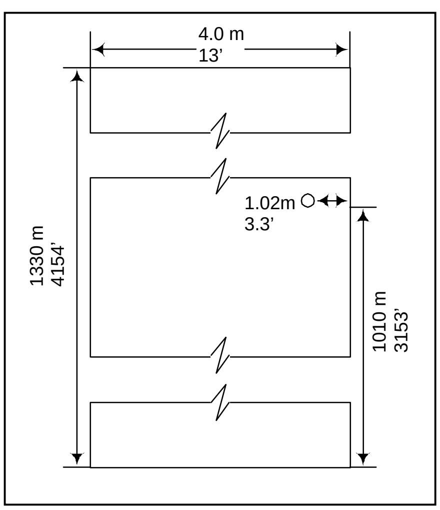
10 **Sampling from a Belt or Flowing Stream:** Agencies specify the frequency of sampling in terms of time, volumes, or masses. The specification might call for one sample from every 1,000,000 kg(1000 t) or 1100 Tons(T) of aggregate. If the random number was 0.317, the

sample would be taken at (0.317)(1,000,000 kg) = 317,000 kg (317 t). Or (.317) (1100 T) = 349 T.

One sample per day might also be specified. If the day were 9 hours long and the random number 0.199, the sample would be taken at (0.199)(9 hrs) = 1.79 hr = 1 hr, 48 minutes into the day. AASHTO T 2 permits this time to be rounded to the nearest 5 minutes.

11 **Sampling from Haul Units:** Based on the agency's specifications – in terms of time, volume, or mass – determine the number of haul units that comprise a lot. Multiply the selected random number(s) by the number of units to determine which unit(s) will be sampled.

For example, if 20 haul units comprise a lot and one sample is needed, pick one RN. If the RN were 0.773, then the sample would be taken from the (0.773) (20) = 15.46, or 16th haul unit.



Sampling from a roadway

Sampling from a Roadway with Previously
12 **Placed Material:** The agency's specified frequency of sampling – in time, volume, or mass – can be translated into a location on a job. For example, if a sample is to be taken every 800 m^3 ($1000yd^3$) and material is being placed 0.15 m (0.50') thick and 4.0 m (13') wide, then the lot is 1330 m (4154') long. You would select two RNs in this case. To convert yd^3 to ft^3 multiply by 27.

13

The first RN would be multiplied by the length to determine where the sample would be taken along the project. The second would be multiplied by the width to determine where, widthwise, the
14 sample would be taken. For example, a first RN of 0.759 would specify that the sample would be taken at (0.759)(1330 m) or (4154') = 1010 m or 3153'from the beginning. A second RN of 0.255
15 would specify that the sample would be taken at (0.255)(4.0 m) or (13') = 1.02 m or 3.3'from the

right edge of the material. To avoid problems associated with taking samples too close to the edge, no sample is taken closer than 0.3 m (1') to the edge. If the RN specifies a location closer than 0.3 m (1'), then 0.3 m (1') is added to or subtracted from the distance calculated.

16 **Sampling from a Stockpile:** AASHTO T 2 recommends against sampling from stockpiles. However, some agencies use random procedures in determining sampling locations from a stockpile. Bear in mind that stockpiles are prone to segregation and that a sample obtained from a stockpile may not be representative. Refer to AASHTO T 2 for guidance on how to sample from a stockpile.

17 **In-Place Density Testing:** Agency specifications will indicate the frequency of tests. For example, one test per 500 m^3 (666 yd^3) might be required. If the material is being placed 0.15 m (0.50') thick and 10.0 m (33') wide, then the lot is 333 m (1090') long. You would select two RNs in this case.

18

The first RN would be multiplied by the length to determine where the sample would be taken along the project. The second would be multiplied by the width to determine where, widthwise, the sample would be taken. For example, a first RN of 0.387 would specify that the sample would be taken at (0.387)(333 m) or (1090') = 129 m or (422') from the beginning. A second RN of 0.588 would specify that the sample would be taken at (0.588)(10.0 m) or (33') = 5.88 m or (19') from the
19 right edge of the material. To avoid problems associated with taking samples too close to the edge, no sample is taken closer than 0.3 m (1') to the edge. If the RN specifies a location closer than 0.3 m (1'), then 0.3 m (1') is added to or subtracted from the distance calculated.

SAFETY

The procedures included in this manual may involve hazardous materials, operations, and equipment. The procedures do not address all of the safety issues associated with their use. It is the responsibility of the employer to assess workplace hazards and to determine whether personal protective equipment (PPE) must be used. PPE must meet applicable American National Standards Institute (ANSI) standards, and be properly used and maintained. The employer must establish appropriate safety and health practices, in compliance with applicable state and federal laws, for these procedures and associated job site hazards. Hazardous materials must be addressed in a Hazard Communication program, and Material Safety Data Sheets (MSDS) must be obtained and available to workers. Supervisors and employees should be aware of job site hazards, and comply with their employers safety and health program. The following table identifies some areas that may affect individuals performing the procedures in this manual.

Body Part Affected	Potential Hazards	PPE/Procedures That May Be Appropriate
Head	Falling or fixed overhead objects; electrical shock	Hard hat or other protective helmet
Eyes and Face	Flying objects, radiation, molten metal, chemicals	Safety glasses, goggles, face shields; prescription or filter lenses
Ears	Noise	Ear plugs, ear muffs
Respiratory System	Inhalation of dusts, chemicals; O_2 deficiency	Properly fit and used respiratory protection consistent with the hazard
Skin	Chemicals including cement; heat	Appropriate chemical or heat resistant gloves, long-sleeve shirts, coveralls
Mouth, digestive system	Ingestion of toxic materials	Disposable or washable gloves, coveralls; personal hygiene
Hands	Physical injury (pinch, cut, puncture), chemicals	Appropriate gloves for physical hazards and compatible with chemicals present
Feet	Falling, sharp objects; slippery surfaces, chemicals	Safety shoes or boots (steel toed, steel shank); traction soles; rubber boots – chemicals, wet conditions
Joints, muscles, tendons	Lifting, bending, twisting, repetitive motions	Proper training and procedures; procedure modifications
Body/Torso	Falls; Burial	Fall protection; trench sloping or shoring
Miscellaneous	Traffic	Visibility, awareness, communication; driver training, safety awareness
Whole body	Radiation	Radiation safety training

TERMINOLOGY

Many of the terms listed below are defined differently by various agencies or organizations. The definitions of the American Association of State Highway and Transportation Officials (AASHTO) are the ones most commonly used in this document.

Absorbed water – Water drawn into a solid by absorption, and having physical properties similar to ordinary water.

Absorption – The increase in the mass of aggregate due to water being absorbed into the pores of the material, but not including water adhering to the outside surface of the particles, expressed as a percentage of the dry mass.

ACC batch plant – A manufacturing facility for producing asphalt cement concrete (ACC) that proportions aggregate by weight and asphalt by weight or volume.

ACC continuous mix plant – A manufacturing facility for producing asphalt cement concrete (ACC) that proportions aggregate and asphalt by a continuous volumetric proportioning system without specific batch intervals.

Acceptance – See verification.

Acceptance program – All factors that comprise the State Highway Agency's (SHA) determination of the quality of the product as specified in the contract requirements. These factors include verification sampling, testing, and inspection and may include results of quality control sampling and testing.

Admixture – Material other than water, cement, and aggregates in portland cement concrete (PCC).

Adsorbed water – Water attached to the surface of a solid by electrochemical forces, and having physical properties substantially different from ordinary water.

Aggregate – Hard granular material of mineral composition, including sand, gravel, slag or crushed stone, used in roadway base and in portland cement concrete (PCC) and asphalt cement concrete (ACC).

- **Coarse aggregate –** Aggregate retained on or above the 4.75 mm (No. 4) sieve.
- **Coarse-graded aggregate –** Aggregate having a predominance of coarse sizes.
- **Dense-graded aggregate –** Aggregate having a particle size distribution such that voids occupy a relatively small percentage of the total volume.
- **Fine aggregate –** Aggregate passing the 4.75 mm (No. 4) sieve.
- **Fine-graded aggregate –** Aggregate having a predominance of fine sizes.
- **Mineral filler –** A fine mineral product at least 70 percent of which passes a 75 µm (No. 200) sieve.

- **Open-graded gap-graded aggregate –** Aggregate having a particle size distribution such that voids occupy a relatively large percentage of the total volume.
- **Well-Graded Aggregate –** Aggregate having an even distribution of particle sizes.

Aggregate storage bins – Bins that store aggregate for feeding material to the dryer in a hot mix asphalt (HMA) plant in substantially the same proportion as required in the finished mix.

Agitation – Provision of gentle motion in portland cement concrete (PCC) sufficient to prevent segregation and loss of plasticity.

Air voids – Total volume of the small air pockets between coated aggregate particles in asphalt cement concrete (ACC); expressed as a percentage of the bulk volume of the compacted paving mixture.

Ambient temperature – Temperature of the surrounding air.

Angular aggregate – Aggregate possessing well-defined edges at the intersection of roughly planar faces.

Apparent specific gravity – The ratio of the mass, in air, of a volume of the impermeable portion of aggregate to the mass of an equal volume of water.

Asphalt – A dark brown to black cementitious material in which the predominate constituents are bitumens occurring in nature or obtained through petroleum processing. Asphalt is a constituent of most crude petroleums.

Asphalt cement – An asphalt specially prepared in quality and consistency for use in the manufacture of asphalt cement concrete (ACC).

Asphalt cement concrete (ACC) – A controlled mix of aggregate and asphalt cement.

Automatic cycling control – A control system in which the opening and closing of the weigh hopper discharge gate, the bituminous discharge valve, and the pugmill discharge gate are actuated by means of automatic mechanical or electronic devices without manual control. The system includes preset timing of dry and wet mixing cycles.

Automatic dryer control – A control system that automatically maintains the temperature of aggregates discharged from the dryer.

Automatic proportioning control – A control system in which proportions of the aggregate and asphalt fractions are controlled by means of gates or valves that are opened and closed by means of automatic mechanical or electronic devices without manual control.

Bag (of cement) – 94 lb of portland cement. (Approximately 1 ft^3 of bulk cement.)

Base – A layer of selected material constructed on top of subgrade or subbase and below the paving on a roadway.

Bias – The offset or skewing of data or information away from its true or accurate position as the result of systematic error.

Binder – Asphalt cement or modified asphalt cement that binds the aggregate particles into a dense mass.

Boulders – Rock fragment, often rounded, with an average dimension larger than 300 mm (12 in.).

Bulk specific gravity – The ratio of the mass, in air, of a volume of aggregate or compacted HMA mix (including the permeable and impermeable voids in the particles, but not including the voids between particles) to the mass of an equal volume of water.

Bulk specific gravity (SSD) **–** The ratio of the mass, in air, of a volume of aggregate or compacted HMA mix, including the mass of water within the voids (but not including the voids between particles), to the mass of an equal volume of water. (See saturated surface dry.)

Cementitious Materials – cement and pozzolans used in concrete such as; Portland Cement, fly ash, silica fume, & blast-furnace slag.

Clay – Fine-grained soil that exhibits plasticity over a range of water contents, and that exhibits considerable strength when dry. Also, that portion of the soil finer than 2 µm.

Cobble – Rock fragment, often rounded, with an average dimension between 75 and 300 mm (3 and 12 in.).

Cohesionless soil – Soil with little or no strength when dry and unconfined or when submerged, such as sand.

Cohesive soil – Soil with considerable strength when dry and that has significant cohesion when unconfined or submerged.

Compaction – Densification of a soil or hot mix asphalt (HMA) by mechanical means.

Compaction curve (Proctor curve or moisture-density curve) – The curve showing the relationship between the dry unit weight or density and the water content of a soil for a given compactive effort.

Compaction test (moisture-density test) – Laboratory compaction procedure in which a soil of known water content is placed in a specified manner into a mold of given dimensions, subjected to a compactive effort of controlled magnitude, and the resulting density determined.

Compressibility – Property of a soil or rock relating to susceptibility to decrease in volume when subject to load.

Constructor – The builder of a project. The individual or entity responsible for performing and completing the construction of a project required by the contract documents. Often called a contractor, since this individual or entity contracts with the owner.

Crusher-run – The total unscreened product of a stone crusher.

Delivery tolerances – Permissible variations from the desired proportions of aggregate and asphalt cement delivered to the pugmill.

Density – The ratio of mass to volume of a substance. Usually expressed in kg/m^3.

Design professional – The designer of a project. This individual or entity may provide services relating to the planning, design, and construction of a project, possibly including materials testing and construction inspection. Sometimes called a "contractor", since this individual or entity contracts with the owner.

Dryer – An apparatus that dries aggregate and heats it to specified temperatures.

Dry mix time – The time interval between introduction of aggregate into the pugmill and the addition of asphalt cement.

Durability – The property of concrete that describes its ability to resist disintegration by weathering and traffic. Included under weathering are changes in the pavement and aggregate due to the action of water, including freezing and thawing.

Effective diameter (effective size) – D_{10}, particle diameter corresponding to 10 percent finer or passing.

Embankment – Controlled, compacted material between the subgrade and subbase or base in a roadway.

End-result specifications – Specifications that require the Constructor to take the entire responsibility for supplying a product or an item of construction. The Owner's (the highway agency's) responsibility is to either accept or reject the final product or to apply a price adjustment that is commensurate with the degree of compliance with the specifications. Sometimes called performance specifications, although considered differently in highway work. (See performance specifications.)

Field operating procedure (FOP) – Procedure used in field testing on a construction site or in a field laboratory. (Based on AASHTO or NAQTC test methods.)

Fineness modulus – A factor equal to the sum of the cumulative percentages of aggregate retained on certain sieves divided by 100; the sieves are 150, 75, 37.5, 19.0, 9.5, 4.75, 2.36, 1.18, 0.60, 0.30, and 0.15 mm. Used in the design of concrete mixes. The lower the fineness modulus, the more water/cement paste that is needed to coat the aggregate.

Fines – Portion of a soil or aggregate finer than a 75 µm (No. 200) sieve. Also silts and clays.

Free water – Water on aggregate available for reaction with hydraulic cement. Mathematically, the difference between total moisture content and absorbed moisture content.

Glacial till – Material deposited by glaciation, usually composed of a wide range of particle sizes, which has not been subjected to the sorting action of water.

Gradation (grain-size distribution) – The proportions by mass of a soil or fragmented rock distributed by particle size.

Gradation analysis (grain size analysis or sieve analysis) – The process of determining grain-size distribution by separation of sieves with different size openings.

Hot aggregate storage bins – Bins that store heated and separated aggregate prior to final proportioning into the mixer.

Hot mix asphalt (HMA) – High quality, thoroughly controlled hot mixture of asphalt cement and well-graded, high quality aggregate.

Hydraulic cement – Cement that sets and hardens by chemical reaction with water.

Independent assurance – Unbiased and independent evaluation of all the sampling and testing procedures, equipment, and technicians involved with Quality Control (QC) and Verification/Acceptance.

In situ – Rock or soil in its natural formation or deposit.

Liquid limit – Water content corresponding to the boundary between the liquid and plastic states.

Loam – A mixture of sand, silt and/or clay with organic matter.

Lot – A quantity of material to be controlled. It may represent a specified mass, a specified number of truckloads, or a specified time period during production.

Manual proportioning control – A control system in which proportions of the aggregate and asphalt fractions are controlled by means of gates or valves that are opened and closed by manual means. The system may or may not include power assisted devices in the actuation of gate and valve opening and closing.

Materials and methods specifications – Also called prescriptive specifications. Specifications that direct the Constructor to use specified materials in definite proportions and specific types of equipment and methods to place the material.

Maximum size – One sieve larger than nominal maximum size.

Mesh – The square opening of a sieve.

Moisture content – The ratio, expressed as a percentage, of the mass of water in a material to the dry mass of the material.

Nominal maximum size – One sieve larger than the first sieve to retain more than 10 percent of the material using an agency specified set of sieves based on cumulative percent retained. Where large gaps in specification sieves exist, intermediate sieve(s) may be inserted to determine nominal maximum size.

> ***Note:*** - The first sieve to normally retain more than 10% of the material usually is the second sieve in the stack but may be the third sieve.

Nuclear gauge – Instruments used to measure in-place density, moisture content, or asphalt content through the measurement of nuclear emissions.

Optimum moisture content (optimum water content) – The water content at which a soil can be compacted to a maximum dry density by a given compactive effort.

Organic soil – Soil with a high organic content.

Owner – The organization that conceives of and eventually operates and maintains a project. A State Highway Agency (SHA) is an Owner.

Paste – Mix of water and hydraulic cement that binds aggregate in portland cement concrete (PCC).

Penetration – The consistency of a bituminous material, expressed as the distance in tenths of a millimeter (0.1 mm) that a standard needle vertically penetrates a sample of the material under specified conditions of loading, time, and temperature.

Percent compaction – The ratio of density of a soil, aggregate, or HMA mix in the field to maximum density determined by a standard compaction test, expressed as a percentage.

Performance specifications – Specifications that describe how the finished product should perform. For highways, performance is typically described in terms of changes over time in physical condition of the surface and its response to load, or in terms of the cumulative traffic required to bring the pavement to a condition defined as “failure.” Specifications containing warranty/guarantee clauses are a form of performance specifications.

Plant screens – Screens located between the dryer and hot aggregate storage bins that separate the heated aggregates by size.

Plastic limit – Water content corresponding to the boundary between the plastic and the semisolid states.

Plasticity – Property of a material to continue to deform indefinitely while sustaining a constant stress.

Plasticity index – Numerical difference between the liquid limit and the plastic limit and, thus, the range of water content over which the soil is plastic.

Portland cement – Hydraulic cement produced by pulverizing portland cement clinker.

Portland cement concrete (PCC) – A controlled mix of aggregate, portland cement, and water, and possibly other admixtures.

PCC batch plant – A manufacturing facility for producing portland cement concrete.

Prescriptive specifications – See Materials and Methods specification.

Proficiency samples – Homogeneous samples that are distributed and tested by two or more laboratories. The test results are compared to assure that the laboratories are obtaining the same results.

Pugmill – A shaft mixer designed to mix aggregate and cement.

Quality assurance – Planned and systematic actions necessary to provide confidence that a product or service will satisfy given requirements for quality. The overall system for providing quality in a constructed project, including Quality Control (QC), Verification/Acceptance, and Independent Assurance (IA).

Quality assurance specifications – Also called QC/QA specifications. A combination of end-result (performance) specifications and materials and methods (prescriptive) specifications. The Constructor is responsible for quality control, and the Owner (highway agency) is responsible for acceptance of the product.

Quality control (QC) – Operational, process control techniques or activities that are performed or conducted to fulfill contract requirements for material or equipment quality.

Random sampling – Procedure for obtaining non-biased, representative samples.

Sand – Particles of rock passing the 4.75 mm (No. 4) sieve and retained on the 75 µm (No. 200) sieve.

Saturated surface dry (SSD) – Condition of an aggregate particle, asphalt cement concrete (ACC) or portland cement concrete (PCC) core, or other porous solid when the permeable voids are filled with water, but no water is present on exposed surfaces. (See bulk specific gravity.)

Segregation – The separation of aggregate by size resulting in a non-uniform material.

SHRP – The Strategic Highway Research Program (SHRP) established in 1987 as a five-year research program to improve the performance and durability of roads and to make those roads safe for both motorists and highway workers. SHRP research funds were partly used for the development of performance-based specifications to directly relate laboratory analysis with field performance.

Sieve – Laboratory apparatus consisting of wire mesh with square openings, usually in circular or rectangular frames.

Silt – Material passing the 75 µm (No. 200) sieve that is non-plastic or very slightly plastic, and that exhibits little or no strength when dry and unconfined. Also, that portion of the soil finer than 75 µm and coarser than 2 µm.

Slump – Measurement related to the workability of concrete.

Soil – Sediments or unconsolidated accumulations of solid particles produced by the physical and chemical disintegration or rocks, and which may or may not contain organic matter.

Specific gravity – The ratio of the mass, in air, of a volume of a material to the mass of an equal volume of water.

Stability – The ability of an asphalt cement concrete (ACC) to resist deformation from imposed loads. Stability is dependent upon internal friction, cohesion, temperature, and rate of loading.

Stratified random sampling – Procedure for obtaining non-biased, representative samples in which the established lot size is divided into equally-sized sublots.

Subbase – A layer of selected material constructed between the subgrade and the base coarse in a flexible HMA roadway, or between the subgrade and portland cement concrete (PCC) pavement in a rigid PCC roadway.

Subgrade – Natural soil prepared and compacted to support a structure or roadway pavement.

Sublot – A segment of a lot chosen to represent the total lot.

Superpave™ – Superpave™ (Superior Performing Asphalt Pavement) is a trademark of the Strategic Highway Research Program (SHRP). Superpave™ is a product of the SHRP asphalt research. The Superpave™ system incorporates performance-based asphalt materials characterization with design environmental conditions to improve performance by controlling rutting, low temperature cracking and fatigue cracking. The three major components of Superpave™ are the asphalt binder specification, the mix design and analysis system, and a computer software system.

Theoretical maximum specific gravity – The ratio of the mass of a given volume of asphalt cement concrete (ACC) with no air voids to the mass of an equal volume of water, both at a stated temperature.

Topsoil – Surface soil, usually containing organic matter.

Uniformity coefficient – C_u, a value employed to quantify how uniform or well-graded an aggregate is: $C_u = D_{60}/D_{10}$. 60 percent of the aggregate, by mass, has a diameter smaller than D_{60} and 10 percent of the aggregate, by mass, has a diameter smaller than D_{10}.

Unit weight – The ratio of weight to volume of a substance. The term “density” is more commonly used.

µm – Micro millimeter (micron) Used as measurement for sieve size.

Vendor – Supplier of project-produced material that is other than the constructor.

Verification – Process of sampling and testing performed to validate Quality Control (QC) sampling and testing and, thus, the quality of the product. Sometimes called Acceptance.

Viscosity – A measure of the resistance to flow; one method of measuring the consistency of asphalt.

- **Absolute viscosity –** A method of measuring viscosity using the "poise" as the basic measurement unit. This method is used at a temperature of 60°C, typical of hot pavement.

- **Kinematic viscosity –** A method of measuring viscosity using the stoke as the basic measurement unit. This method is used at a temperature of 135°C, typical of hot asphalt at a plant.

Void in the mineral aggregate (VMA) – The volume of inter-granular void space between aggregate particles of compacted asphalt cement concrete (ACC) that includes air and asphalt; expressed as a percentage of the bulk volume of the compacted paving mixture.

Voids filled with asphalt – The portion of the void in the mineral aggregate (VMA) that contains asphalt; expressed as a percentage of the bulk volume of mix or the VMA.

Wet mixing period – The time interval between the beginning of application of asphalt material and the opening of the mixer gate.

Zero air voids curve (saturation curve) – Curve showing the zero air voids density as a function of water content.

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